UNCLASSIFIED

AD 149999

Armed Services Technical Information Agency

ARLINGTON HALL STATION
ARLINGTON 12 VIRGINIA

FOR
MICRO-CARD
CONTROL ONLY

1 OF 1

UNCLASSIFIED

DISCLAIMER NOTICE

NAVORD REPORT 5752

BEHAVIOUR OF POWDERED AND FLAKE MAGNETIC CORES AT TEMPERATURES UP TO 500°C

17 OCTOBER 1957

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

BEHAVIOUR OF POWDERED AND FLAKE MAGNETIC CORES AT TEMPERATURES UP TO 500°C

Prepared by:

John F. Haben and Edmond Adams

ABSTRACT: The magnetic characteristics of seven high permeability (55-300) powdered and flake core materials were measured at 50°C temperature intervals up to 500°C. Three low permeability (13-22) Carbonyl iron "E" cores for higher frequency (> 100 KC) operation were also examined. Of the seven core materials tested for <100 KC applications, Sendust powder showed the least irreversible change in permeability and eddy current coefficient after cycling to 500°C. None of the cores tested were stable for operation at elevated temperatures, although (μQ) curves showed that the Flakenol core was the most constant over the temperature range. The commercially available 2-81 Mo-Permalloy and Sendust powder cores were less constant. The magnetic characteristics of the high and low frequency carbonyl iron cores insulated with plastic binders were seriously degraded above 225°C. Although the cores tested were unstable above 250°C in varying degrees, the copper conductor material and its insulation appears to be the limiting factor for continuous 500°C operation.

U. S. NAVAL ORDNANCE LABORATORY
White Oak, Silver Spring, Maryland

This report summarizes the changes in the magnetic characteristics of powdered and flake magnetic cores at intervals up to 500°C. This study was undertaken for the information of the Navy under BuOrd Task No. 503-725/54025-101040 and BuShips Project NOL-266, because no information was available on the temperature stability of powdered magnetic cores above 200°C for use in high frequency applications.

W. W. WILBOURNE
Captain, USN
Commander

Louis R. Maxwell

L. R. MAXWELL
By direction

CONTENTS

ILLUSTRATIONS

TABLES

BEHAVIOUR OF POWDERED AND FLAKE MAGNETIC CORES AT TEMPERATURES UP TO 500°C

INTRODUCTION

1. The principal requirement of magnetic powder cores in most inductor applications is that their magnetic characteristics remain relatively constant with changes in temperature, humidity, flux level and frequency. Of all these factors, it was considered most urgent to determine the effects of temperature since many electronic components may have to operate at temperatures as high as 500°C. Although some effects of temperature on powdered core inductors have been measured[1,2], these were confined to a narrow temperature range, the maximum limit usually not exceeding 190°C. Therefore, the changes in permeability, total loss factor and eddy-current loss coefficient were determined for various representative magnetic powdered and flake core materials over a temperature range of 25° - 500°C. Most of the samples represent core materials for use at low flux densities and at frequencies up to 100 KC/S. In addition, three powdered carbonyl iron cores for use at higher frequencies (0.5 - 35 mc/s) were also examined. The data for these cores are presented in the Appendix. Table I lists the core materials that were evaluated in this study.

EXPERIMENTAL MEASUREMENTS

2. Because the temperature stability of magnetic powdered cores varies to some extent with core dimensions, whenever possible, samples of equal size were selected. The dimensions are shown in Table I.

3. The toroids were wrapped with glass tape insulation and wound with 25 turns of AWG #30 "Silotex" (Anaconda Copper Type DX Class H) wire. Silotex is the trade name applied to magnet wire insulated with alkali-free glass fiber yarn and bonded with silicone varnish. Although it is rated at 180°C "hottest spot temperatures", motors wound with Silotex magnet wire have operated continuously at over 200°C without impairing the insulation.

4. The cores were placed in a laboratory box furnace capable of operating up to 1200°C with a heat zone of 3" x 4" x 10". They were arranged so that each core and respective leads were separated from its neighbors. Since the maximum temperature selected (500°C) was outside of the wire manufacturer's specifications, every effort was made not to disturb the cores and leads after positioning. After completion of the high temperature measurements, it was found that the insulation had deteriorated and the copper wire was extremely brittle and fragile.

TABLE I

TYPES AND DIMENSIONS OF MAGNETIC CORES EVALUATED

CORE				DIMENSIONS (cm)		
No.	MATERIAL	Mfg.	μ	O.D.	I.D.	Ht.
1	Sendust Powder 5.5%Al, 9.5%Si, Bal Fe	TMI	55	3.20	1.98	0.83
2	Mo-Permalloy * 2% Mo, 81 Ni, Bal Fe	AE	120	2.72	1.47	1.15
3	Carbonyl Iron GS-6	NOL	70	5.10	4.11	0.51
4	16-Alfenol Powder 16 Al, Bal. Fe	NOL	115	5.10	4.11	0.56
5	13.9-Alfenol Flake 13.9 Al, Bal. Fe	NOL	300	2.72	1.47	0.71
6	Flakenol (Sendust Flake)	NOL	220	2.72	1.47	0.51
7	Flakenol * (Sendust Flake)	NOL	150	2.72	1.47	0.72
8	Carbonyl Iron "E"	CGW	13	2.34	1.31	0.59
9	Carbonyl Iron "E"	EQ-1	22	2.37	1.60	0.40
10	Carbonyl Iron "E"	TC-1	21	2.39	1.60	0.39

* Temperature Stabilized

Manufacturer:

TMI = Tohoku Metal Industries, Japan

AE = Arnold Engineering Company, Marengo, Illinois

NOL = Naval Ordnance Laboratory, White Oak, Maryland

CGW)
EQ-1) Furnished by Navy, Bureau of Ships
TC-1)

5. The magnetic characteristics measured with respect to temperature were (1) permeability (2) total loss factor ($^R/_u Lf$) and (3) Legg's eddy-current coefficient (e). It has become standard practice to measure these properties in compacted ferromagnetic powders and ferrites by means of a single-layer winding upon a toroidal specimen of the material. The permeability, total loss factor ($^R/_u Lf$), and eddy current coefficient (e) can be determined from r.f. bridge measurements of the current, inductance, and resistance of the toroidal winding. The values that appear in this report were obtained by methods based on work by Elmen[3], Legg[4] and Owens[5]. A block diagram of the measurement circuit appears in Figure 1. The equipment used in this study was as follows:

(1) Maxwell h.f. Bridge, Western Electric W-10094-6

(2) Beat Frequency Generator, Boonton, Type 140-A

(3) VTVM, Hewlett Packard, Type 400H

(4) Modified Burrell Globar Type Box Furnace.

6. In obtaining the a-c loss component of the core material itself by the above method, the shorted inductance of the bridge must be subtracted from the inductance of the toroidal winding. In a similar manner, the shorted bridge resistance must be subtracted from the a-c resistance of the toroidal winding. The d-c resistance of the toroidal winding must also be subtracted from the a-c bridge resistance value. Because of the change in resistance with temperature, a d-c resistance reading was obtained at each test temperature.

7. The temperature was raised in 50°C steps and the cores were allowed to soak for approximately one hour at each temperature. Since the measurements were made over a period of a week, at the close of each working day the cores were allowed to remain overnight at the last measured temperature. The next morning the inductance of each core was remeasured; no significant changes were found over the previous readings. At each temperature the inductance and a-c resistance were determined for each toroid at three frequencies; 25, 50 and 75 KC/S. (Figs. 3-9). The temperature was increased until a substantial decrease in permeability occurred at around 500°C. This temperature was approximately the Curie temperature for most of the test samples except for the carbonyl iron core which has a Curie Temperature of 770°C. At the end of the study the furnace was allowed to cool to room temperature overnight. The inductance and resistance of the cores were then remeasured at 25, 50 and 75 KC/S to determine the amount of temperature hysteresis which occurred. Since the percentage change was about the same at each frequency, the permeability and loss data shown in Table II are for 25 KC/S only.

TABLE II

MAGNETIC CHARACTERISTICS BEFORE AND AFTER HEATING TO 500°C

No.	Core Material	μ *	$\frac{R \times 10^6}{\mu L f}$ *	e x 10^9	Percentage Change μ	Percentage Change $\frac{R \times 10^6}{\mu L f}$	Percentage Change e x 10^9
1	Sendust Powder	56.4	264	13			
		56.0	237	13	-0.71	-10.2	0
2	Mo-Permalloy **	117	452	16			
		103	468	19	-12.0	3.5	18.8
3	Carbonyl Iron GS-6	67.3	254	4.7			
		80.3	16600	890.	19.3	6400	18800
4	16-Alfenol Powder	114	1240	33			
		100	1350	35	-12.3	8.9	6.0
5	13.9 Alfenol Flake	306	1550	53			
		232	1590	56	-24.2	2.6	5.7
6	Flakenol I	222	270	6.5			
		187	294	5.3	-15.8	8.9	-18.5
7	Flakenol I **	154	395	7.8			
		137	587	7.7	-11.0	48.6	-1.3

* 25 KC/S; B = 5 gauss

** Temperature Stabilized

NOTE: The data on the first line for each core material gives the values before heating; the second line gives values after heating.

DISCUSSION OF RESULTS

8. Permanent Effects of 500°C Exposure. The amount of irreversible changes in the magnetic properties of the powdered and flake cores after exposure to 500°C is summarized in Table II. The inductor material least affected by this severe temperature cycle was the Sendust powder. The carbonyl iron core, because its organic insulation deteriorated, became virtually useless as an inductor core material. Although the eddy current losses increased tremendously the a-c permeability remained fairly constant presumably because of eddy current shielding.

9. The other core materials showed a moderate decrease in permeability and some increase in the total loss factor. It is interesting to note that the Flakenol I cores showed a decrease in the eddy current loss coefficient although the total loss factor increased. Although they were not measured, an increase in the hysteresis and residual losses would account for this increase.

10. Permeability. The variations in permeability with increase in temperature for the seven cores are shown in Figure 2. The details of the temperature effects on the most important magnetic characteristics for each core material are given in Figures 3 - 9. The permeability of most of the cores tested dropped sharply at temperatures near their Curie point of 450 - 500°C. Although the permeability of the carbonyl iron core appears stable at 25 KC/S in Figure 2, Figure 5 shows that at higher frequencies the permeability decreases because of eddy current shielding.

11. As can be seen in Figure 7, there is an anomaly in the 13.92 Alfenol Flake core. The permeability drops to 60 percent of the room temperature value at about 200°C and then recovers 90 percent of its original value at the higher temperature. This phenomenon has been observed in other Alfenol cores and may be related to stress relief and to the order-disorder transformations occurring in the alloy during the temperature cycling.

12. The data in Figure 6 confirms the temperature stability of the Alfenol powder core to about 120°C. However, the inductance dropped off rapidly as the temperature was increased.

13. Eddy Current and Total Losses. In addition to the permeability changes at each temperature, Figures 3 - 9 show the temperature effects on the total loss factor at 25, 50 and 75 KC/S and eddy current coefficient (e) for each core material. For most of the core materials, the losses decreased with temperature, then rapidly increased at the higher temperature. The carbonyl iron core, however, deteriorated rapidly after 150°C was reached.

14. Quality Factor (μQ). Three of the best materials of this temperature study were selected for comparison on the basis of the quality factor (μQ) as suggested by Owens[5]. The resultant curves in Figure 10 show that the Sendust powder and Mo-Permalloy cores are comparable over the temperature range tested. Flakenol I appears to have a slightly higher and more constant (μQ) over the other two materials shown.

SUMMARY AND CONCLUSION

15. The limiting factors in the use of powdered and flake cores for high temperature inductor applications are:

1. Curie temperature of the magnetic material
2. Particle insulation breakdown
3. Conductors and their insulation.

The Curie temperature limitation of the core material can be probably overcome by the use of iron or cobalt-iron base alloys. Refractory insulations of the type used in 2-81 Mo-Permalloy cores should be considered for use in the iron powder cores instead of the present plastic binders.

16. Although no core material tested met all the requirements for a powdered core inductor, Sendust powder, 2-81 Mo-Permalloy and Flakenol were the most stable. On the basis of μQ curve in Figure 10, the constancy of the Flakenol curve over the other two makes it an excellent core material for use at high temperatures.

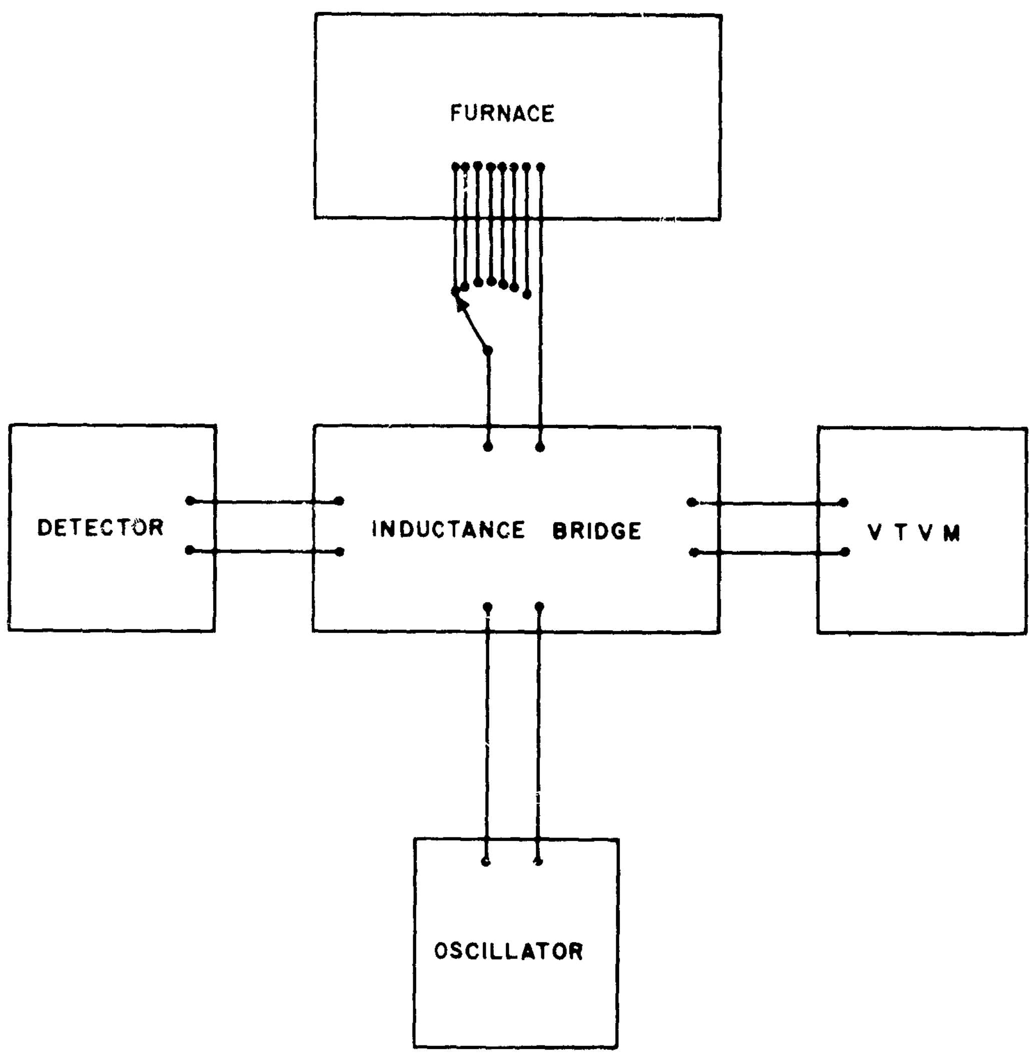

FIG. 1 EQUIPMENT BLOCK DIAGRAM

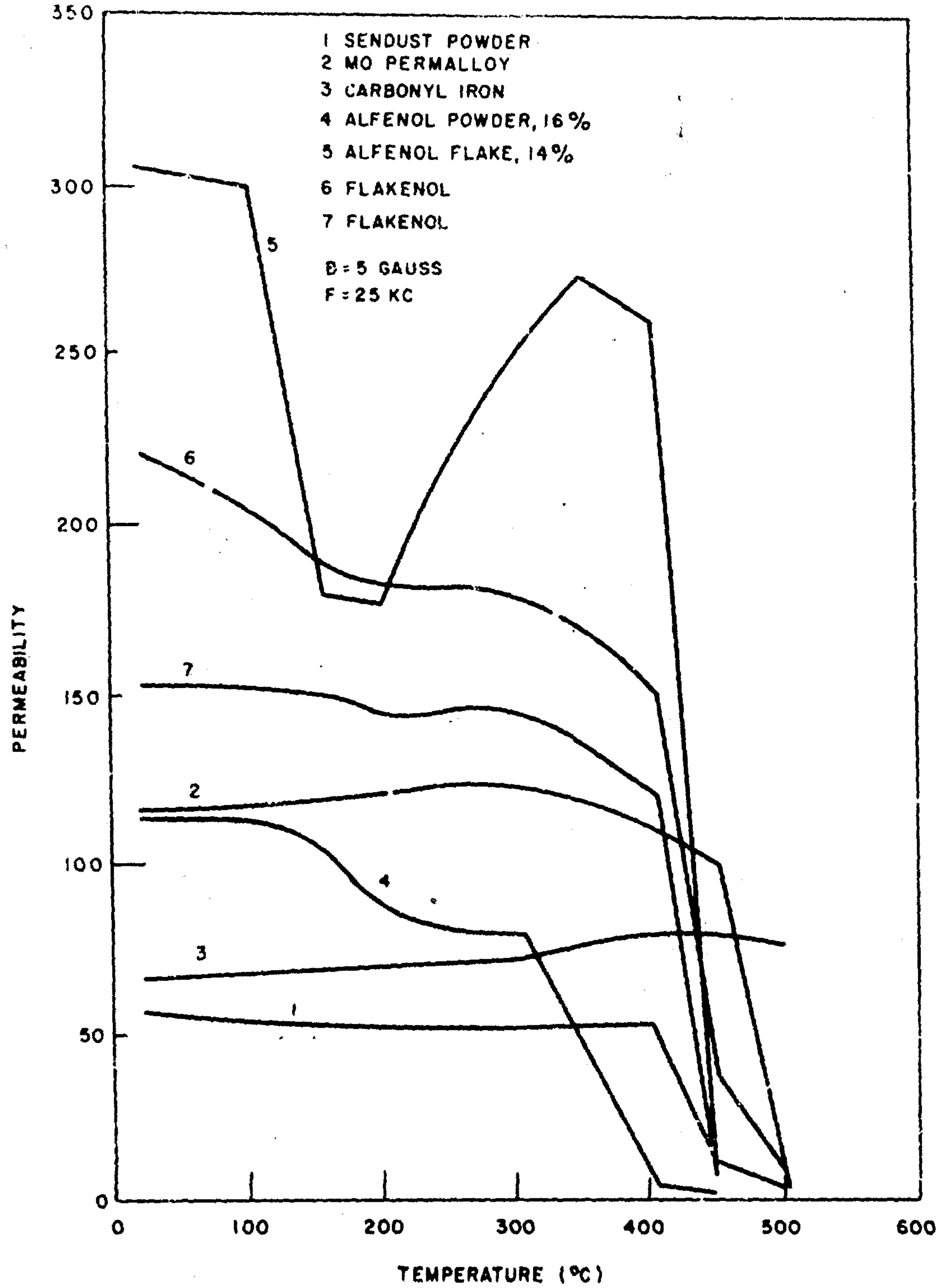

FIG. 2 EFFECT OF TEMPERATURE ON PERMEABILITY (ALL CORES)

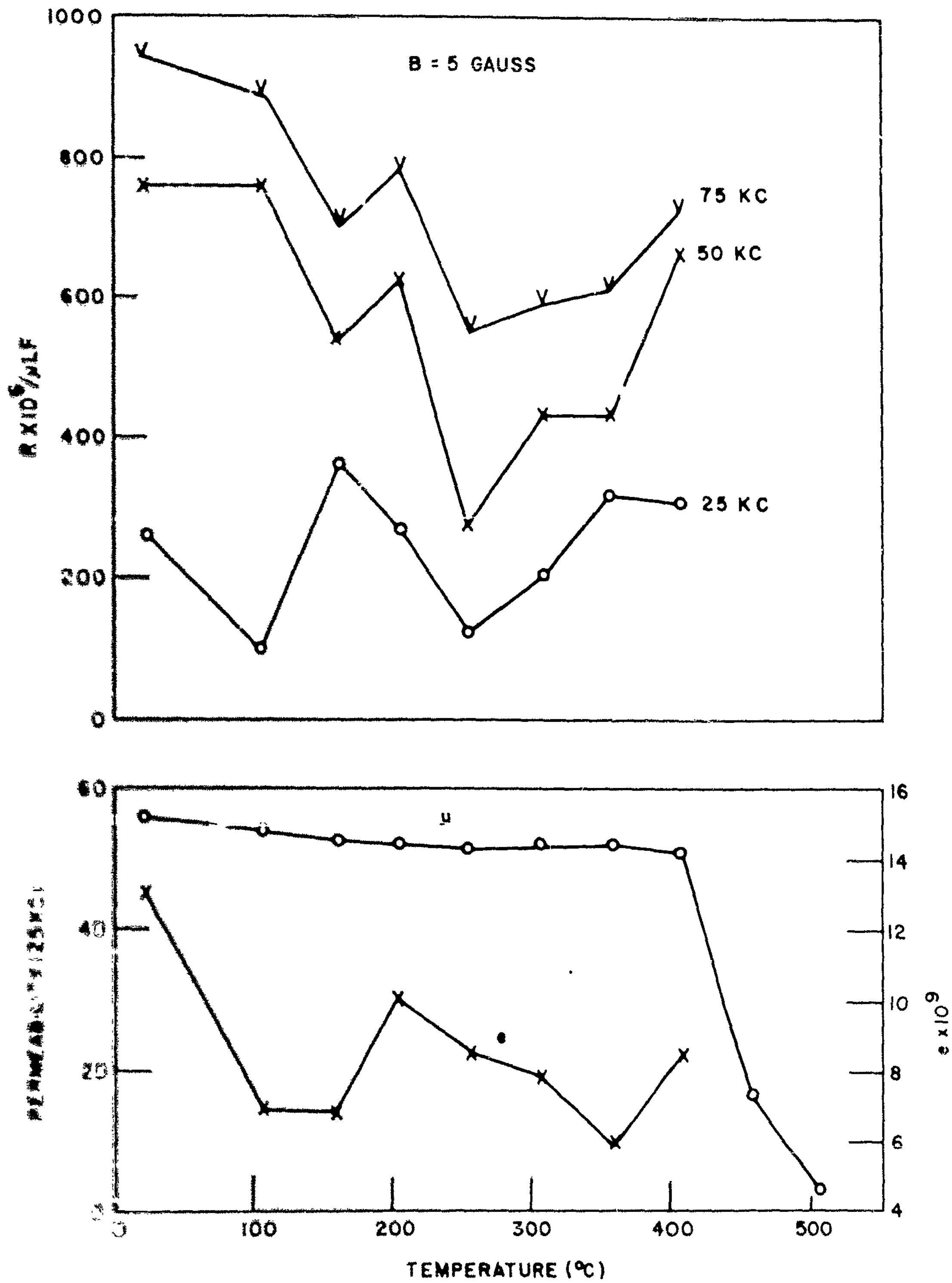

FIG. 3 TEMPERATURE EFFECTS (SENDUST POWDER)

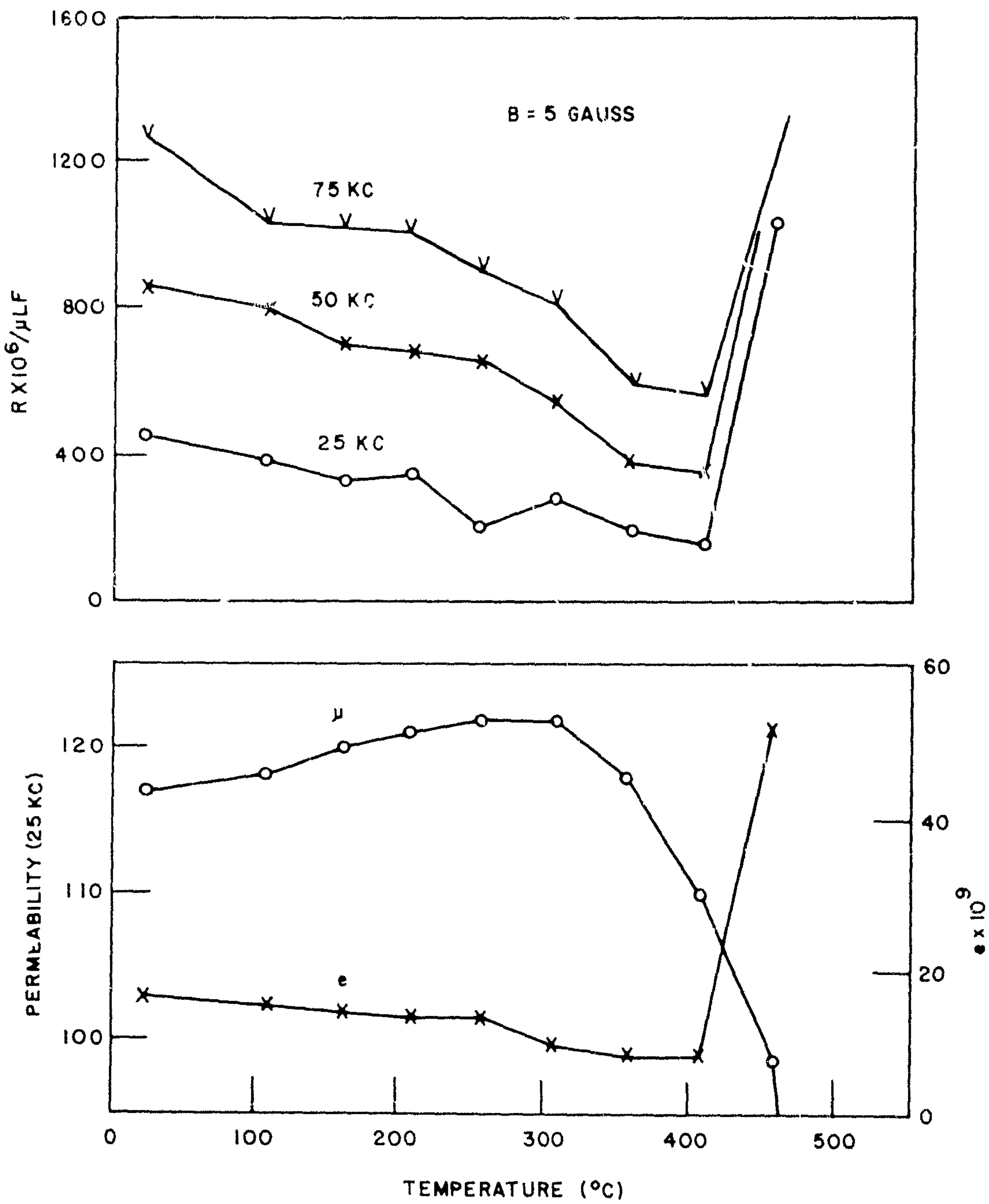

FIG. 4 TEMPERATURE EFFECTS (MO PERMALLOY)

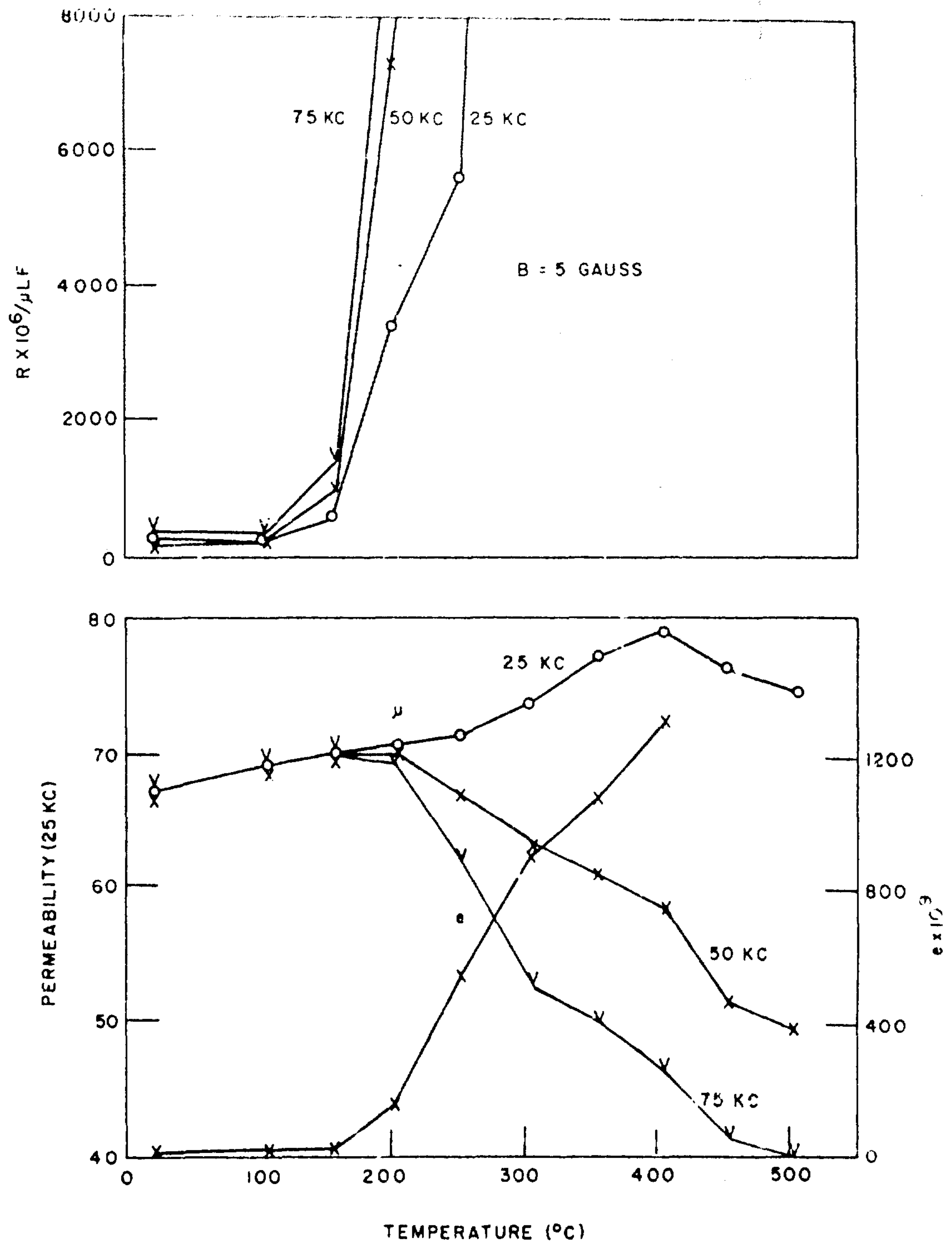

FIG. 5 TEMPERATURE EFFECTS (CARBONYL IRON)

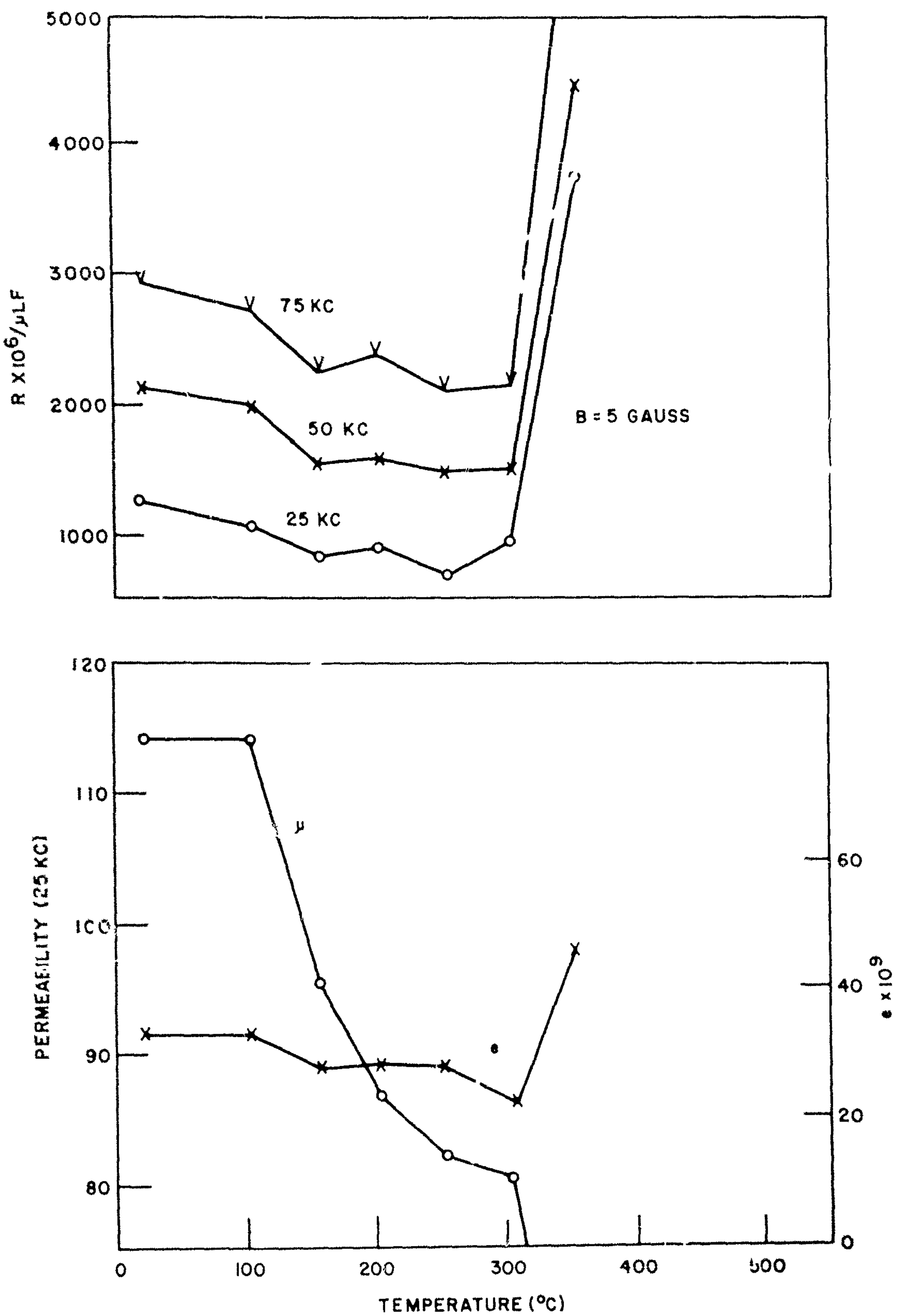

FIG. 6 TEMPERATURE EFFECTS (ALFENOL POWDER-16%)

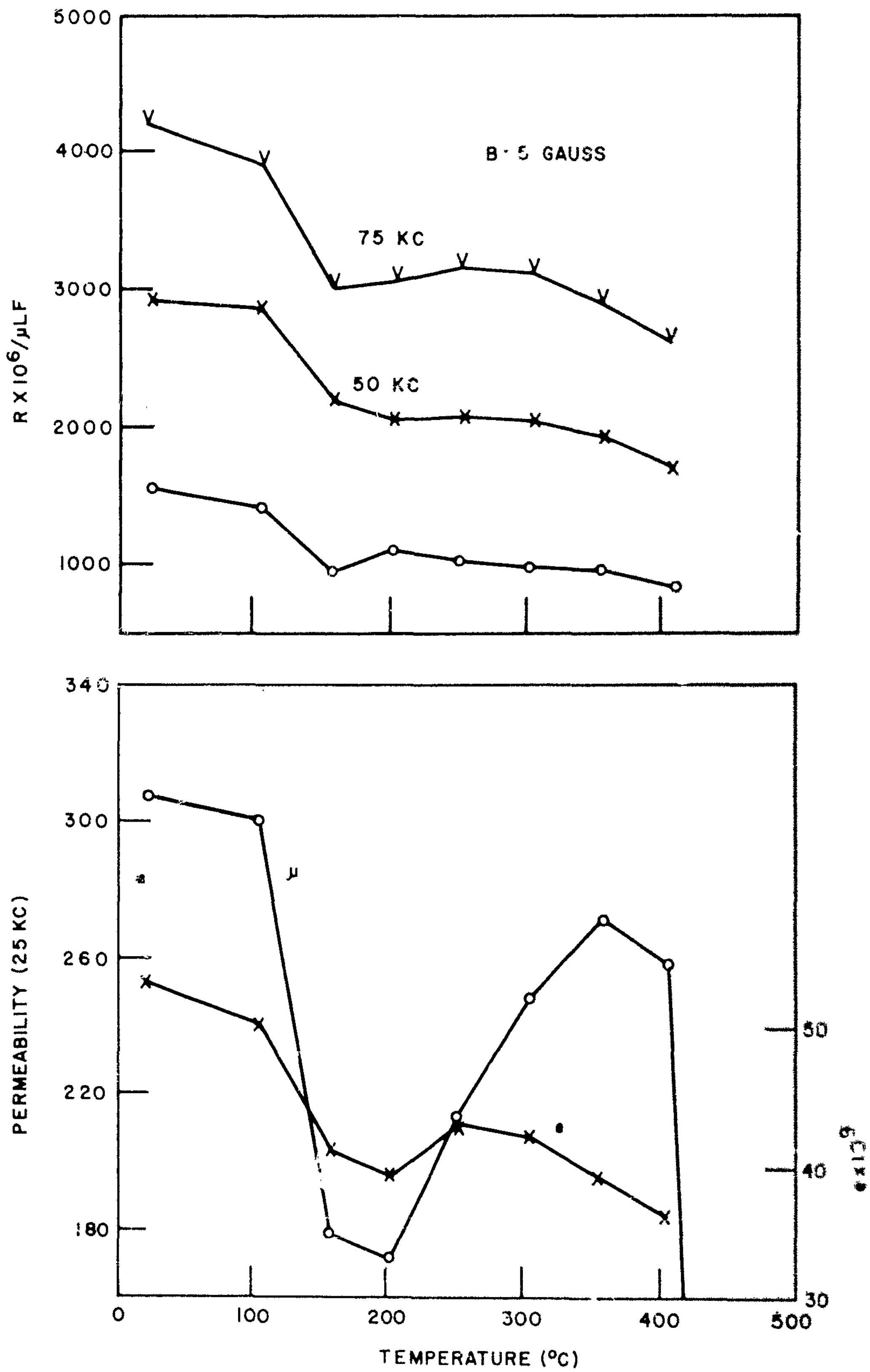

FIG. 7 TEMPERATURE EFFECTS (ALFENOL FLAKE-14%)

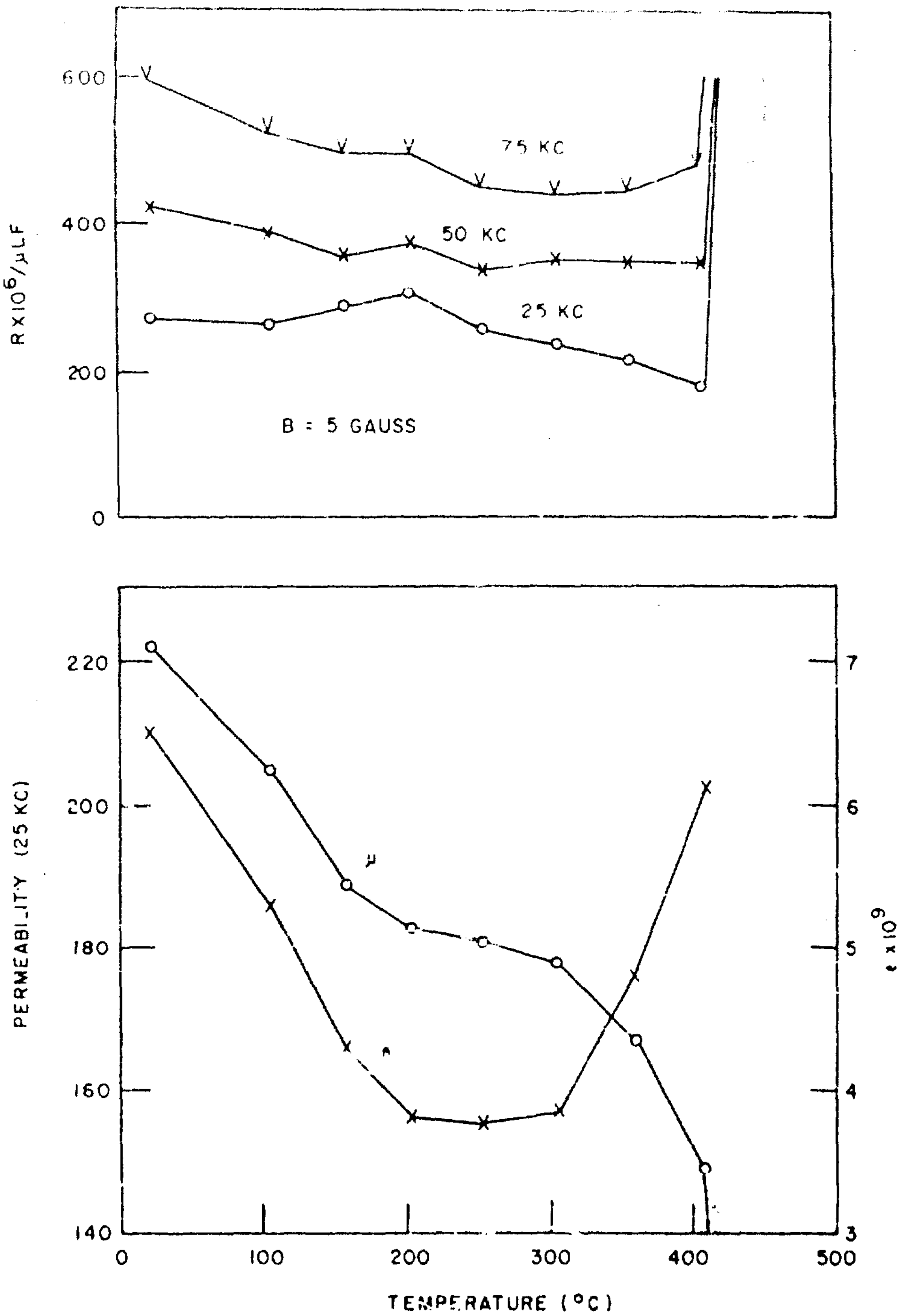

FIG. 8 TEMPERATURE EFFECTS (FLAKENOL)

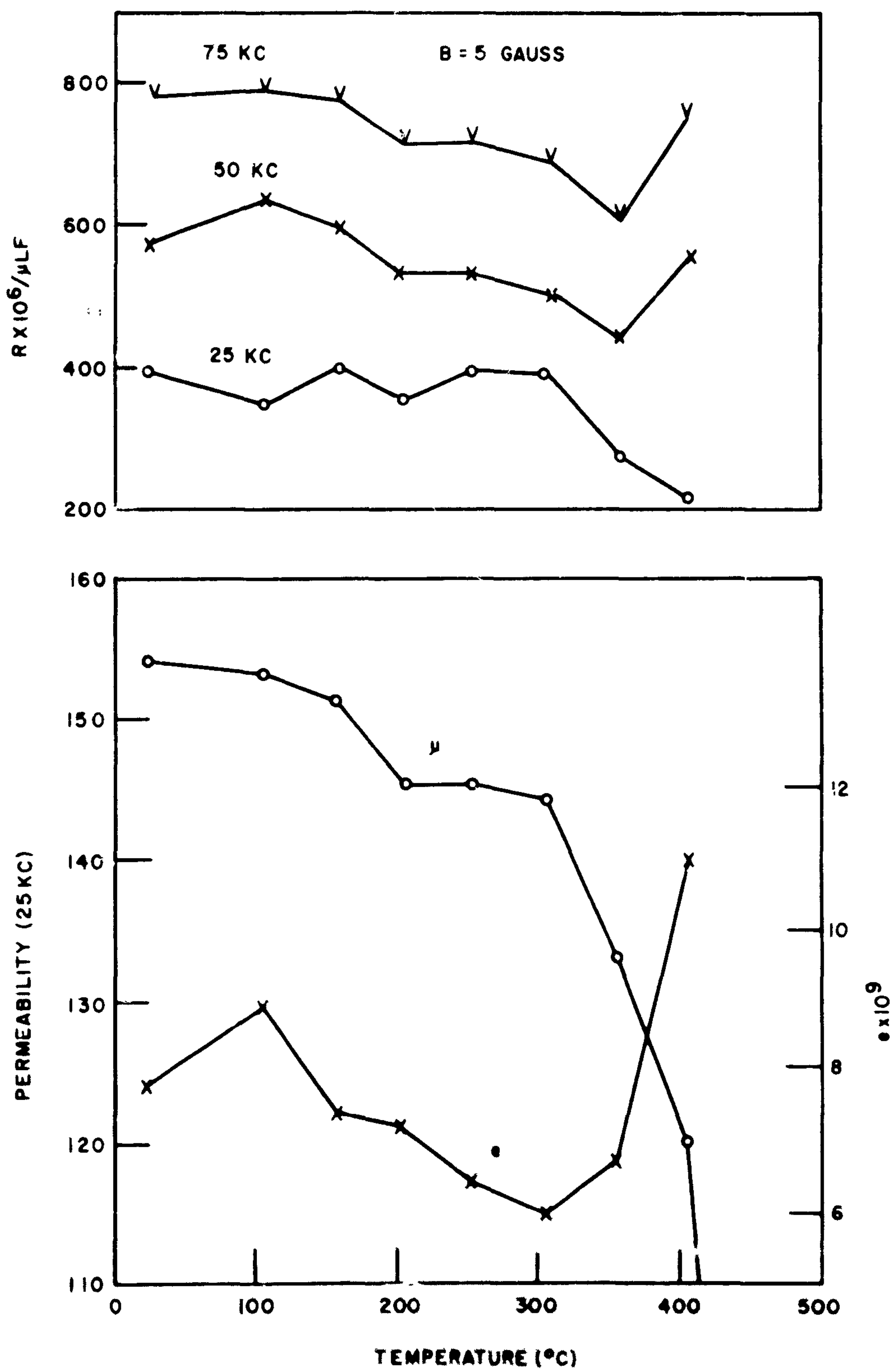

FIG. 9 TEMPERATURE EFFECTS (FLAKENOL)

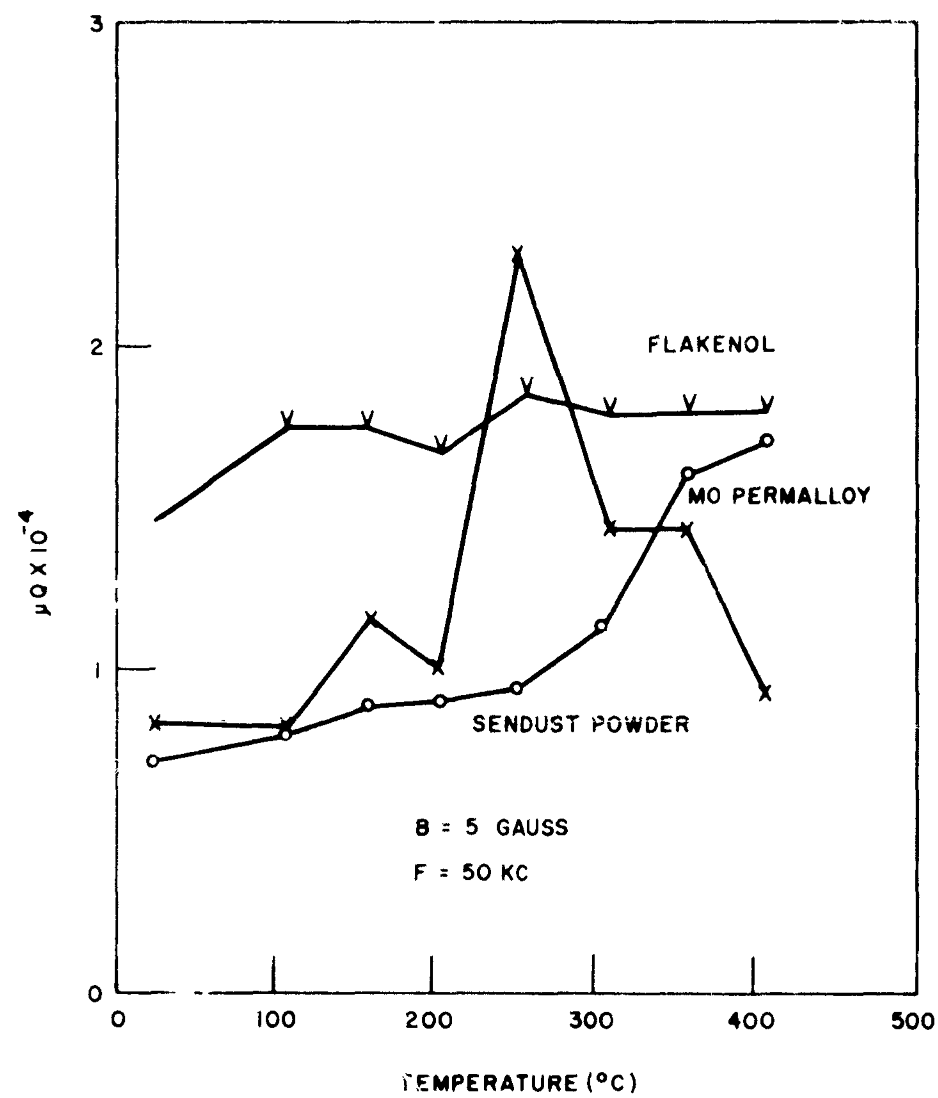

FIG. 10 EFFECT OF TEMPERATURE ON QUALITY FACTOR (μQ)

REFERENCES

1. "Molybdenum Permalloy Powder Cores" Bulletin PC-104A, March 15, 1955 Arnold Engineering Co., Marengo, Illinois.

2. Katz, George "Effect of Temperature on Iron Powder Cores" Electrical Manufacturing, Vol. 56, No. 2, 1954.

3. Elmen, G. W. and Speed, B., "Magnetic Properties of Compressed Powdered Iron" Transactions AIEE, Vol. 40, pp 596 (1921).

4. Legg, V. E., "Magnetic Measurements at Low Flux Densities Using the A.C. Bridge", Bell System Tech. Journal, Vol. 15, pp 39-62, Jan. 1936.

5. Owens, C. D., "Analysis of Measurements on Magnetic Ferrites", I.R.E. Vol. 41, No. 3 pp 359-365, March 1953.

APPENDIX I

EFFECT OF TEMPERATURE ON HIGH FREQUENCY
CARBONYL IRON CORES

1. The effects of temperature on various magnetic parameters were reported in the preceeding pages on powdered cores useful in the lower frequency range (< 100 KC/S). Since a large volume of powdered inductors is used in the higher frequency range of 0.5 to 35 mc/s, three carbonyl iron cores used in that range were examined. The cores tested are listed in Table I of the main report.

2. The same test procedure was followed as described for the lower frequency core materials, except the test frequency was 500 KC/S. The higher frequency used, along with the long leads from the furnace to the bridge and inter-winding capacitance introduced some errors in the absolute values of permeability and losses. However, since these errors remained constant, the effects of temperature on these magnetic properties can be noted in a relative manner. These results can be seen in Figure 11.

Discussion of Results

3. It can be seen from Figure 11 that for the two plastic bonded iron cores, there is a sharp increase in permeability and the total loss factor from about 250°C to 500°C. This is due to the decomposition of the plastic binder and insulation. The decrease that follows at 500°C is probably due to the partial conversion of the iron particles to the higher resistivity, unidentified magnetic iron oxides. The degradation of the glass insulated carbonyl iron core is more uniform denoting a more temperature resistant insulation. The permeability of this core also seems to be more stable up to 225°C than for the plastic bonded cores.

Summary and Conclusion

4. Figure 11 shows that none of the three cores tested are acceptable for high frequency used above 225°C. Not only do the present refractory insulations and organic binders break down, but the fine carbonyl iron particles are very reactive and therefore have poor oxidation resistance with increase in temperature. It is expected that only second order improvement would result from the use of higher temperature binders, such as silicone or fluorocarbon resins.

5. On the basis of their excellent magnetic characteristics and resistance to oxidation, heavily insulated fine particles of Sendust and 2-81 Mo-Permalloy composition should also be examined for use at the high frequency range in place of carbonyl iron.

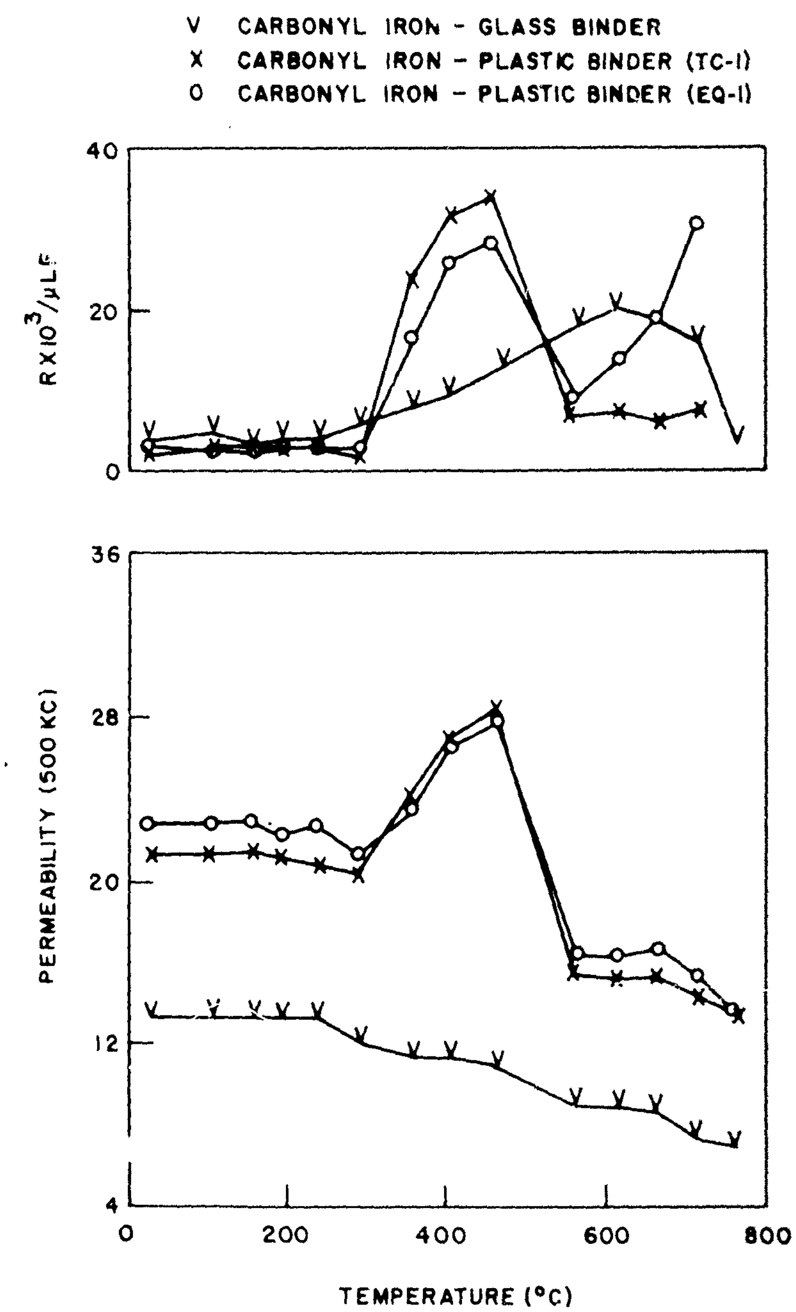

FIG. 11 TEMPERATURE EFFECTS (CARBONYL IRON "E")